

Digging for formational clues in the halos of early-type galaxies

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Abstract. Many of the fundamental properties of early-type galaxies (ellipticals and lenticulars) can only be accessed by venturing beyond their oft-studied centers into their large-radius halo regions. Advances in observations of kinematical tracers allow early-type halos to be increasingly well probed. This review focuses on recent findings on angular momentum and dark matter content, and discusses some possible implications for galaxy structure and formation.

Keywords: galaxies: halos – galaxies: elliptical and lenticular, cD – galaxies: kinematics and dynamics – galaxies: fundamental parameters – galaxies: formation – dark matter

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INTRODUCTION

The Milky Way’s halo has for a century been a Rosetta stone for deciphering the structure and formational history of our home galaxy by using multitudes of individual stars as chemo-dynamical tracers. Recent observational advances have extended this “archaeological” approach to Local Group galaxies including the massive spiral M31. The ultimate goal is the study of resolved stellar populations in all galaxy types and environments, whose fruition will require the next generation of giant telescopes. In the meantime a great deal of information can be learned through the alternatives of integrated stellar light [1–4], and resolved tracers such as planetary nebulae (PNe; [5–7]) and globular clusters (GCs; [8]).

These observational tools are particularly apt for delving into massive early-type galaxies (ellipticals and lenticulars), whose evolutionary histories are challenging to understand in a cosmological context. A simple paradigm where gas-rich disk galaxies fade to lenticulars, or merge into ellipticals, is giving way to a more complex picture where minor mergers and secular processes play critical roles [9–12]. To decrypt the varied genealogies of low redshift galaxies, some of the key fossil clues are the halo distributions of angular momentum and mass (including dark matter), orbit structures, metallicity gradients, and substructures such as streams and shells.

The cornerstones of such halo studies are high-quality, deep, wide-field imaging and spectroscopy, detailed modeling, and comparison to simulations of galaxy formation. Large surveys of early-type galaxy halos are currently underway at the Keck, Subaru, and William Herschel telescopes, using stars, GCs, and PNe: SMEAGOL, SLUGGS, and the PN.S Elliptical Galaxy Survey [1, 4–8]. These projects complement the central surveys by SAURON [13, 14] and enable the construction of comprehensive global galactic models.

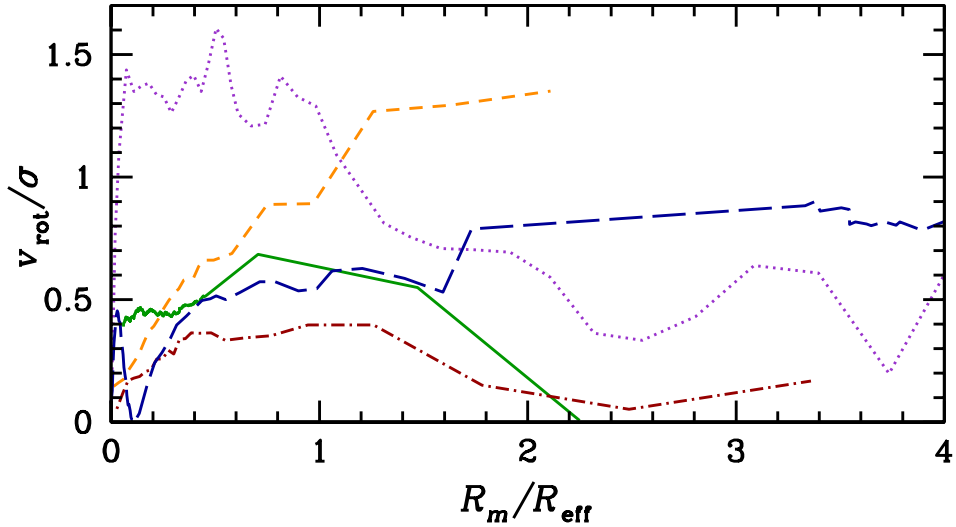


FIGURE 1. Rotation dominance parameter (major-axis rotation amplitude over velocity dispersion) versus radius for a sample of early-type galaxies, selected to illustrate the range of outer rotation profiles observed [1, 2, 6]. All cases are classified as fast-rotators based on their central regions.

ANGULAR MOMENTUM

The central regions of early- and late-type galaxies differ dramatically in their rotational properties, which may reflect differences in angular momentum conservation during their assembly histories [15]. Among the early-types, there are two broad sub-types: the fainter, diskly, fast-rotators with cuspy centers; and the brighter, boxy, slow-rotators with central cores. The SAURON survey has dramatically demonstrated this distinction based on kinematics and dynamics, motivating an angular momentum metric as the primary classifier for galaxies [13, 14].

The fast-rotators are characterized as oblate axisymmetric systems which are likely shaped by dissipative processes, as in a major gas-rich (“wet”) merger. The slow-rotators are triaxial with surprisingly isotropic orbits, with so far no formation model that fully explains their properties, although it is plausible that they originated in multiple mergers at high redshift [16].

The advent of larger-radius kinematical data now suggests that standard rotation-based classifications may be relevant only for the central regions. The rotation profiles outside of an effective radius (R_{eff}) are diverse, including common cases of “fast-rotators” where the outer rotation amplitude drops dramatically (Fig. 1), yielding global specific angular momentum values that are comparable to those of the slow rotators (and still much smaller than in late-types). There are also hints of kinematic twists appearing at large radii [6], suggesting an onset of triaxiality.

These observations concord with photometric results for many diskly ellipticals to transition to rounder and boxier spheroids at large radii. There is a long-standing model wherein all early-types can be characterized primarily as extended bulges, often with an additional central disklike component [17–19]. The large-radius kinematics dramatically

confirm this picture and suggest that the bulge rotation tends to be fairly *slow* outside the central regions (where the disk and bulge may be coupled).

A number of formational possibilities are suggested by this weakly-coupled two-component picture of early-type galaxies. Recent analysis of 1:1 wet merger simulations demonstrates that in this classic scenario, an observable decoupling between the central and outer regions is naturally expected—reflecting the wet and dry components of the merger, respectively [20]. Growth of the outer envelope by minor mergers may produce a similar effect. Another possibility is that stream-fed high-redshift “wild disks” [9, 10] might build up a bulge with rotation decreasing outwards. It remains to be seen in detail how these various scenarios’ predictions for rotation amplitudes and twists square with observations. One potential degeneracy breaker is the use of GC subpopulations, since these would originate in different components of the galactic progenitors [20, 21].

DARK MATTER

The dark matter (DM) content of ordinary early-type galaxies is much more poorly known than for late-types. Although some constraints have been provided by gravitational lensing and X-ray gas emission, there is a critical need for detailed DM profiles in an unbiased sample of galaxies. The radially extended dynamics of stars, PNe, and GCs are starting to fill this void. Despite systematic modeling difficulties in deriving robust DM constraints, independent efforts are so far returning consistent results [2, 7], and further progress will come through combining multiple tracers in the same galaxies.

The hodgepodge of results so far available in the literature paint a startling picture of the DM content in early-types (Fig. 2). The slow-rotators appear to have much higher halo concentrations than the fast-rotators, with the theoretical prediction treated as a zone of avoidance. Other inferences from more central regions are not consistently supportive of these large-radius results [23–25], which may in fact be highly skewed by observational selection effects—demonstrating the need for an unbiased survey.

If the dichotomy does hold up in an unbiased sample, it would not be explained merely by some kind of preferential population of DM halos. Instead, systematic differences would be implied in the interplay between baryons and DM during galaxy assembly, affecting the central DM densities. Contraction of the halo during baryonic collapse would have been efficient in slow rotators, but not in fast-rotators or in late-types (see Fig. 2). There have been many mechanisms proposed for inefficient halo contraction, with the dynamical effects of lumpy accretion emerging as a major contender [26]. In this case, a history of smoother accretion might be implied for the slow rotators.

Another puzzle involves the halo *orbits* of stars and GCs: fast rotators show radial bias as expected [2, 5, 7], but the slow rotators may be isotropic or *tangentially*-biased [8]. Piecing together all these clues should help decipher galaxies’ formational pathways.

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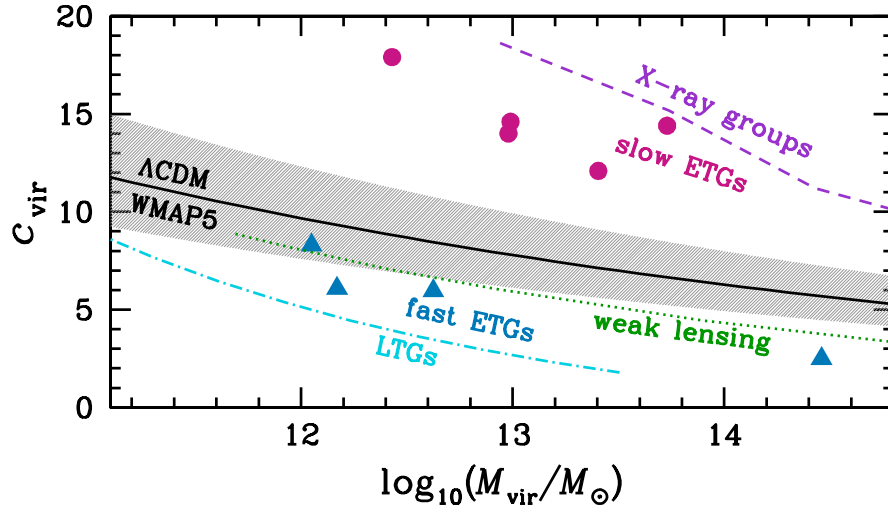


FIGURE 2. Dark matter halo masses and concentrations for early-type galaxies based on dynamics [5], with shading showing updated theoretical predictions [22]. The slow- and fast-rotators are shown with different symbols and labeled accordingly. The error bars in this parameter space are large and correlated because of the extrapolations to the virial radius, but a re-casting to well-constrained central dark matter parameters shows a similar dichotomy between the fast- and slow-rotators. For comparison, independent results are shown for X-ray groups (which typically have central slow-rotators) and for late-type galaxies. A mean trend for both early- and late-types based on weak gravitational lensing is also included.

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